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Search for Higgs-like particle produced in association with b quarks and measurement of $Z \to b\bar{b}$ cross section at CDF II

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We present a search for a Higgs-like particle ϕ decaying into $b\bar{b}$ produced in association with b quarks in $p\bar{p}$ collisions. The event sample corresponds to 5.4 fb^{-1} of integrated luminosity collected with the CDF II detector at the Tevatron collider using a single b tagged jet trigger. We search for an enhancement in the mass of the two leading jets in event with at least three jets identified as coming from b quarks. A data-driven procedure is applied to estimate the dijet mass spectrum of the non-resonant multijet background, which has been used to measure the production cross-section of the Z decaying into $b\bar{b}$ in the same sample but with at least two b-jets. We set one of the most stringent upper limits on $\sigma(p\bar{p} \to \phi b) \times \mathscr{B}(\phi \to b\bar{b})$ in the $100-300$ GeV/c^2 mass range.

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1. Introduction

The CDF experiment [1] took data at the Tevatron proton anti-proton collider until the 2011 at an energy in the center of mass of $\sqrt{s} = 1.96$ TeV. It has been the first experiment at a hadron collider developing a trigger processor to select at the on-line level events containing a secondary vertex formed by long lived particles [2]. By exploiting this, a dataset enriched of b-jets corresponding to 5.4 fb^{-1} of integrated luminosity, has been collected. This sample gives the unique opportunity to search for resonances decaying into b-jets pairs in the low mass region, difficult nowadays for the ATLAS and CMS experiments at the LHC due to the larger QCD background. The first measurement presented in this contribution is the determination of the cross section of the inclusive $Z \to b\bar{b}$ process, which is also used to validate the whole analysis technique. With the same selection then, an upper limit on the inclusive Standard Model $H \to b\bar{b}$ process is set. Finally, the search for a beyond Standard Model scalar particle ϕ, produced in association with b quarks and decaying into a $b\bar{b}$ pair, is reported.

2. Measurement of the inclusive $Z \to b\bar{b}$ cross section

The Z boson has been studied at hadron colliders predominantly using the leptonic decays into muons or electrons. In fact, the hadronic decays are much more difficult to separate from the overwhelming background arising from generic jet pairs produced by the multijet QCD production. The identification and the measurement of the inclusive $Z \to b\bar{b}$ process represents a real challenge, but on the other hand it allows to have a standard candle to validate the analysis procedure, the background modeling and to measure the b-jet energy scale (JES).

The dataset has been collected with a trigger which, by exploiting the long lifetimes of B-hadrons, performed an on-line b-tagging in order to efficiently select events with b-jets while keeping low thresholds on the jet energies. At the off-line level, the hadronic jets are reconstructed by using the standard CDF II prescription, with the cone radius parameter of $R = 0.7$.

The signal is searched in events that are required to have at least two central jets, $|\eta| < 1$, with $E_{\mathrm{T}} > 22$ GeV and with a secondary vertex identified by the tight off-line b-tagging algorithm (SecVxt [3]). This sample, called double tagged sample, is predominantly constituted by QCD heavy quarks jets. A precise prediction of the production rates for the different QCD mechanisms is difficult to obtain. It is not possible then to simply use the Monte Carlo simulation, scaled to the Standard Model predictions, to determine the background composition. Moreover, the modeling of the background has also to include all the biases introduced by the trigger and the off-line selection. For these reasons, the analysis is based on a data-driven technique.

The method proceeds as follow:

- the probabilities, as function of jet E_{T} and η, to tag a $b-$, $c-$, light-quark (q) initiated jet as a $b-$jet are determined by using the Monte Carlo simulated data. These per jet probabilities represent the efficiency to tag (b, c or q initiated jet) as a $b-$jet and are referred as tagging matrices;

- starting from a single on-line and off-line b-tagged jet data sample, the flavour-dependent bias introduced by the SecVtx tagging is simulated on the non-tagged jet by weighting it with the tagging matrices for b, c, q jets;

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- the invariant mass of the b-tag trigger and the flavour tagged-simulated jets is calculated under the different jet flavour hypotheses.

With this method only the shapes of the background are determined, normalizations are found in the final fit and are one of the results of the analysis. Since the invariant mass distribution templates built with the b-tagging and the c-tagging matrices are very similar and the fit is not able to distinguish them, they are merged. A systematics is assigned for this assumption. Finally, to model the QCD multijet background 4 different templates are used:

(Bb+Bc) - (bB+cB) - Bq - qB

where capital letter indicates the b-tagged jet that also fired the trigger.

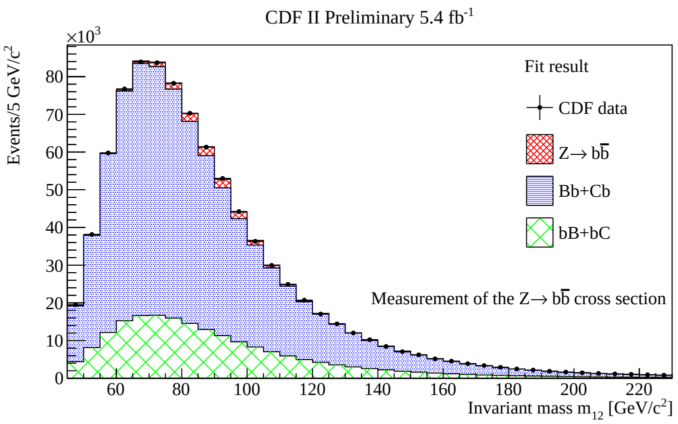

Figure 1: Double tagged events invariant mass distribution with the result of the fit.

The final fit to the double tagged is performed using a binned maximum-likelihood function, using a $Z \to b\bar{b}$ signal template taken from MC in addition to the background templates. Figure 1 shows the result of the fit, $(16.5 \pm 1.2) \times 10^3$ signal events are found. Including also the systematic uncertainties, the significance of the signal is greater than 5σ. The cross section times the branching ratio is then measured as:

$$\sigma_Z \times \mathscr{B}(Z \to b\bar{b}) = 1.11 \pm 0.08(stat) \pm 0.13(sys) \text{ nb}, \tag{2.1}$$

which is consistent with the NLO theoretical calculation [4] combined with the measured $Z \to b\bar{b}$ branching ratio, which predicts a value of 1.13 ± 0.02 nb. The JES has been measured as well and has been found to be $0.993 \pm 0.022(stat) \pm 0.008(sys)$.

3. Upper limit on the inclusive $H \to b\bar{b}$ process

The same dataset, with the same event selection and background modeling can be used to extract information about the inclusive production of the Higgs boson into a b-quark pair. At Tevatron the predicted total Standard Model Higgs production cross section is 1.23 ± 0.22 pb [5], more than 3 order of magnitude smaller with respect to the $Z \to b\bar{b}$ process. Given the integrated luminosity of 5.4 fb^{-1}, we expect about 36 signal events in the final dataset. Due to the extremely small S/B, no Higgs events are expected to be found.

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A 95% confidence level (C.L.) upper limit on the inclusive production of the Standard Model Higgs is set using a modified frequentist CL_S method. The compatibility of the data with the background only and background plus signal hypothesis is tested by constructing a test statistic, t, which in this case is the difference in χ^2 of the fits in the background only and background plus signal hypotheses. The systematic uncertainties, which can affect both the normalization and the template shapes, are introduced in the limit calculator as nuisance parameters. The expected and observed CL_s obtained as a function of the ratio between the cross section upper limit and the Standard Model cross section are presented in Figure 2. The observed(expected) upper limit at 95% C.L. on the $p\bar{p} \to H \to b\bar{b}$ is found to be 33(46) times the standard model cross section.

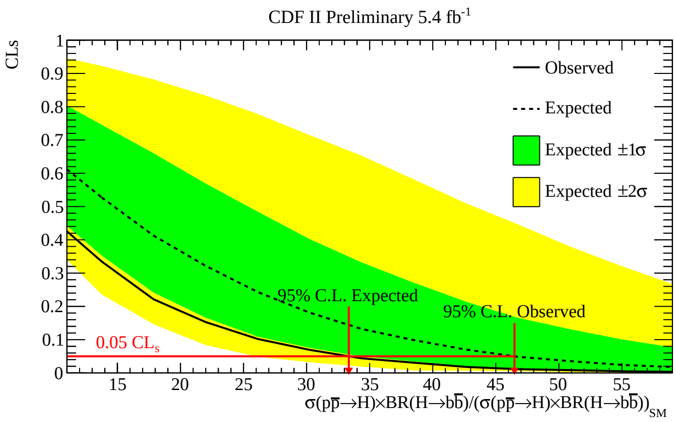

Figure 2: Observed (black solid line) and expected (black dashed line) CL_s as function of the cross section times the branching ratio normalized to SM $H \to b\bar{b}$. The 95% C.L. limits are indicated by the red vertical arrows under the red horizontal line.

4. Higgs-like particle in multi-b final state

A search for a new narrow neutral scalar particle ϕ decaying into b-jets in multi b-jets final states is here described. Because of the various possible theoretical frameworks, the analysis is kept model independent, i.e. the upper limit is set only on the production cross section. Searches in this channel have already been performed by the CDF [6] and D0 [7] experiments and by the CMS [8] experiment at LHC. The two Tevatron experiments have combined their results [9], reporting a deviation, at the level of 2σ, from the Standard Model expectations in the $100 - 150$ GeV$/c^2$ invariant mass range.

The signal is searched as a bump in the invariant mass distribution of the two leading b-jets in a sample of three b-tagged jets. Also in this analysis, the main background is the QCD multijet production of heavy flavour. The same principles described for the $Z \to b\bar{b}$ analysis are used to model the different multijet components, with the caveat that this time the starting point for the templates construction is the double tagged sample. The effect of requiring a third tag, whose efficiency depends upon the flavour of the jet, is simulated using a parametrization of the SecVtx response evaluated using Monte Carlo samples. The flavour composition of the triple tagged jets sample is determined by fitting the data.

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Different signal hypotheses, with a mass range between 100 and 300 GeV/c^2 have been investigated. Background and signal templates are fitted to the data using 2-dimensional binned maximum-likelihood fits, where the two variables are the invariant mass of the leading jets and a second variable built from the invariant mass of the secondary vertex which is sensitive to the flavour of the parton initiating the jet.

No excess has been found, so a 95% confidence level upper limits on the production cross section times the branching ratio of a narrow scalar as a function of the mass has been set, as shown in Figure 3. As for the SM Higgs limit, the limit is based on a modified frequentist CL_S method with the systematic uncertainties included as nuisance parameters. This is the most stringent upper limits on the $\sigma \times \mathscr{B}$ in this mass range.

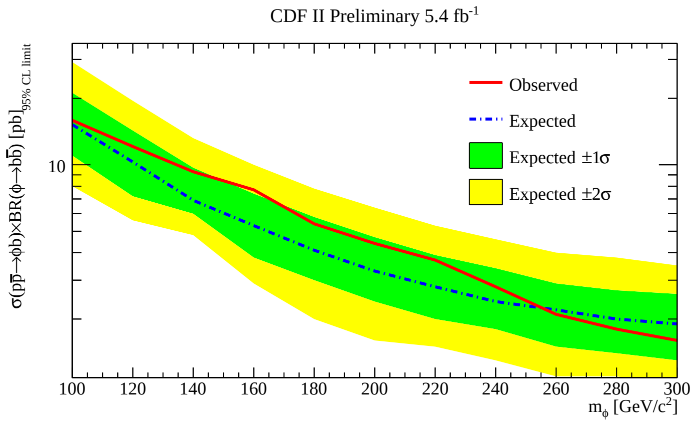

Figure 3: The observed 95% C.L. upper limits on the cross section times the branching ratio.

5. Conclusions

The possibility to reconstruct a secondary vertex already at the on-line level at CDF II allowed to collect a unique sample almost pure in b-jets without the needed to cut hard on the E_T of the jets. Three different measurements using this sample have been performed and they have been presented here. First, the challenging measurement of the $Z \to b\bar{b}$ cross section has been described, which gave also the opportunity to validate the analysis technique and the different tools. The result has been found to be in nice agreement with the Standard Model prediction. By using the same selection and background description then, the inclusive limit on the inclusive Standard Model $H \to b\bar{b}$ process has been set. Finally, the search for a Higgs-like particle decaying into a pair of b-quark jets and produced in association with at least one additional b-quark jet at CDF has been described. No hint of deviation from the SM background expectations has been observed and thus an upper limit on the cross section times branching ratio in the $100-300$ GeV/c^2 mass range is calculated. The result improves the previous combined limit of CDF and D0 and classifies the 2σ excess in the 100-160 GeV mass range as a statistical fluctuation.

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